# Status in 1999 of the
# High Flux Reactor Fuel Cycle

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## ABSTRACT

The High Flux Reactor located at Petten (The Netherlands) is owned by the European Commission and is operated under contract by NRG (Nuclear Research and Consultancy Group).

This plant is in operation since 1962 using HEU. In 1998/1999 calculations were made with a parametric study to try to optimise a LEU element for a progressive conversion of the plant. The parameters of the study were the number of plates by element, the density of the fuel (from silicide 4.8 g/cm$^3$ to UMo 9.1 g/cm$^3$), the meat thickness and the type and quantity of the burnable poison.

The optimum fuel element presented is of 4.8 g/cm$^3$ silicide LEU. The use of this element induces only small penalties on thermal fluxes (less than 5%), enables a longer cycle (28.3 operating days instead of 24.7 operating days in the current HEU cycle length) and complies with all thermal-hydraulic criteria as presently applied for the HEU core.

A working plan has begun with the safety authorities for licensing this new fuel element and the main lines of this plan are also presented.

For the UMo possibilities, a presentation is made of the first calculation results. Test on UMo with a special irradiation device, will also begin and are presented.

For the back-end of the fuel cycle, this paper presents the interim storage in the pools of the plant, and the transportation possibilities to a dry storage.

In conclusion, great progress has been made during this year for a conversion of the plant and for the improvement of MTR fuel in the future.

## 1. Introduction

The HFR located at Petten (The Netherlands) belongs to the Institute for Advanced Materials of the Joint Research Centre (JRC) of the European Commission. The day-to-day operation and maintenance of the plant are carried out under contract by the Nuclear Research and Consultancy Group (NRG).

The HFR is of the tank-in-pool type, light water cooled and moderated. It is operated at 45 MW. In operation since 1961, and following complete refurbishing in recent years, the HFR still has a technical life beyond the year 2015. It is one of the most powerful multipurpose material testing reactors in the world.

The reactor provides a variety of irradiation facilities and possibilities: in the reactor core, in the reflector region, in the poolside. Horizontal beam tubes are available for research, and medical application with neutrons. Gamma irradiation facilities are also available. Excellently equipped hot cell laboratories, on the Petten site, can virtually provide all envisaged post-irradiation examinations.

The close co-operation between the Joint Research Centre and the Nuclear Research and Consultancy Group (NRG) on all aspects of nuclear research and technology is essential to maintain the key position of the HFR amongst research reactors world-wide. This cooperation has lead to a unique HFR structure, in which both organisations are involved with the aim to adopt a more market oriented approach and offer their long standing and recognised competence in exploiting a powerful, reliable set of nuclear facilities to worldwide interested parties.

HFR is also in the core of the Medical Valley association. This association between IAM, NRG, Mallinckrodt and hospitals leads to a medical structure unique in the world, and about 50% of the reactor is already used by medical applications; radio-isotope production, Boron Neutron Capture Therapy, etc.

The present HFR operating schedule consists of 11 cycles of 28 days (24.7 days of full power operation and 3.3 days of core reloading and check-out procedures) and 2 maintenance stops of about 4 weeks resulting in at least 275 days of full power operation per year. The yearly operational plan for the HFR is followed as closely as possible to offer the users a predictable timetable for reliable experimental and isotope production planning.

## 2. Core and fuel description

- The core lattice is a 9 x 9 array (729 mm x 750.4 mm) containing 33 fuel assemblies, 6 control assemblies, 19 experiment positions and 23 beryllium reflector elements. The row at the eastside of the core lattice normally loaded with 9 beryllium reflector elements is arranged outside the core box of the reactor vessel.

- The fuel assemblies (horizontal cross section 81 mm x 77 mm, height 924 mm) contain 23 parallel, curved, fuel plates with an active height of 600 mm.

- Each plate consists of an $UAl_x$-Al matrix with a thickness of 0.51 mm, clad with aluminium of 0.38 mm thickness for the inner plates and 0.57 mm for the outer fuel plates. The uranium is at least 89% enriched in $^{235}U$. The uranium content of the fresh fuel assemblies is 450g$^{235}U$. The two side plates of each fresh fuel assembly contain together 1000 mg: $^{10}B$.

- There are six control assemblies, each of them consists of a cadmium section on top of a fuel section with Al driver section. The fuel section contains 19 fuel plates with a total fresh mass of 310g$^{235}U$. Their drive mechanism is situated below the reactor vessel, giving free access on the top of the reactor. The control assemblies move vertically. When a control assembly is moved upwards, the fuel moves into the core displacing the cadmium section.

- Apart from the 19 in-core irradiation positions, there are 12 irradiation positions at the poolside facility offering stationery as well as transient irradiation conditions. Surrounding the core box, 12 horizontal beam tubes are situated for basic and applied fundamental research and activation analyses. These include dedicated beam tubes for Boron Neutron Capture Therapy and neutron radiography of non-radioactive components and fuel pins.

- The fuel consumption is about 4 (or 5) elements by cycle [Ref. 1] and one control rod by cycle. Therefore, and with eleven cycles/year, the consumption of fuel is about 11 control rods and 50 elements per year.

## 3. HFR conversion studies

### 3.1 Organisation

After a tendering offer in 1998, the first study was made by AEA Technology, (Harwell, U.K.) end 1998 and beginning 1999.

The aim of this study was to have parametric calculation in the neutronic and thermal-hydraulic field, to determine the best proposed choice of LEU fuel element. Then discussions and calculations were held with ANL (Argonne, USA) to confirm the results and to arrive at the last results.

### 3.2 Main results

#### 3.2.1 Parameters

The study was made for a progressive conversion of the core. This point led to a geometric limitation : the assemblies should have the same hydraulic section, to have the same pressure drop.

Therefore, the parameters remaining possible to change were

- density of the fuel. From 4.8 to 6 g/cm$^3$ for the silicide. Up to 9.8 g/cm$^3$ for UMo.
- number of plates. From 23 (actual value) to 19.
- clad thickness.

- choice and quantity of burnable poison.

The main objective was to maintain the fluxes and especially the thermal flux in PSF.

3.2.2 Neutronic calculations

- Results on fluxes and reactivity
  In all cases it was interesting to decrease the level of Boron (Fig. 1).
  Final level was chosen at 200 mg/side-plate.
  Decrease in the number of plates has a positive effect on reactivity and flux, but the differences remain low (Fig. 2).
  Increasing the density of fuel was not so interesting in our case. It should allow the increase of the length of cycles, but it gives some penalties (about 5%) on the thermal flux in PSF. On the other hand the UMo is not yet qualified which could result in possible planning problems.
  Therefore, the best choice at the end of this study was : silicide 4.8 g/cm$^3$ with 19 plates.

- Fuel consumption
  Actually we often use four elements/cycle [Ref. 1]. The parametric calculations were made with 5 elements/cycle. However, to decrease the fuel consumption, we tried to increase the length of the cycle to 28.3 days (actually 24.7 days). This point is also interesting because it allows, in PSF, to have four successive irradiations (7 days) for technetium production.
  In this case the best choice was: 21 plates/4.8 g/cm$^3$ silicide/clad thickness 0.38 mm/meat thickness 0.65 mm and 200 mg $^{10}$B per plate.

- Other consequences
  The gamma fluxes are about the same (less than 3%) of variation (Figs. 3 and 4).
  The power distribution in the core has no significant variation.
  The flux spectrum is very similar. Therefore the disturbance of experiments should be minimal during the progressive conversion.

- Conclusion
  At the end of the parametric studies the first choice with 21 fuel plates elements allows to have about the same fluxes (less than 5% of penalties), with a longer cycle and a reduced increase of fuel consumption.

3.2.3 Thermal-hydraulic studies

When you decrease the number of plates, you increase the power and the flow rate in the same proportion per plate.
When you apply the thermo-hydraulic criteria used on the HFR with usual margins, we have no problems until 21 plates.
Afterwards, for less than 21 plates, there remains a lot of safety margins but the same criteria seems difficult to apply.
This was another reason to choose a 21 plate element.

### 3.2.4 Further optimisation

Work has begun with ANL (Argonne) for a final optimisation on two points

- comparison between 21 and 20 plates
- comparison between the use of Boron or Cadmium wires as burnable poison in the side-plates.

## 3.3 Fuel licensing

As soon as the final optimisation has been done, work will begin to obtain the fuel element licensing.

Firstly, two elements will be ordered as test elements. This test is not a test on the fuel behaviour which is already very well known in the HFR: Simone test [Ref. 2] and test for UKAEA [Ref 3], but more an industrial verification, scale 1, before the conversion.

Secondly, discussions were held with the safety authorities and a working plan was proposed as follows :

Phase I: General information explaining the parametric studies, the reasons for the choice and the final design of the new proposed element.

Phase II: Technical qualification of the fuel element.

During this phase, 9 technical points will be studied which cover all the technical questions related to this new fuel. These 9 points are the following:

1) Neutronic calculations (during progressive conversion and for several cores)
2) Hydraulic pressure drop measurements
3) Thermo-hydraulic calculation (verification of margins)
4) Behaviour of fuel: bibliographic review
5) Mechanical consequences (weight/control-rod and loading)
6) Consequences on experiment safety (BNCT, test, etc.)
7) Consequences on HFR fuel cycle
8) Consequences on accident calculations (change in source term, transient behaviour, etc.)
9) Test of two elements in the reactor to verify fabrication problems and reactivity measurements.

Phase III: Updating of reference documentation.

- Description of the plant
- Safety analysis updating
- Update technical specifications of the plant
- Environmental impact study

## 3.4 Conclusion

The parametric studies have allowed us to find a good candidate for a progressive conversion with a very classical fuel (silicide 4.8 g/cm$^3$), already tested in HFR several times, giving minimal penalties on the fluxes (less than 5%) and increasing cycle length to 28.3 days.

After qualification, the UMo will also be a good candidate for the future.

## 4. HFR fuel testing

- For qualification test of research reactor fuel, HFR has a possibility of test scale 1, or possibility to test separate plates in special devices.
  For this type of test, the High Flux Reactor has many specific advantages [Ref. 4]
  - a large core, providing a variety of interesting positions with high fluence rates
  - a downward coolant flow simplifying the engineering of the device
  - easy access with all handling possibilities to the hot-cells
  - the high number of operating days (>280 days/year), together with the high flux, gives a possibility to reach quickly the high burn-up needs
  - an experienced engineering department capable of translating specific requirements in tailor-made experimental devices
  - a well equipped hot-cell laboratory on site to perform all necessary measurements (swelling, $\gamma$-scanning, etc.) and all destructive examinations.

Figure 5 gives a view of a device made to test four separate plates.

- In the frame of the French supplementary programme, one test with 4 plates will begin before end 1999. This test, names UMUS, will allow to study the behaviour of UMo fuel with different densities and compositions for the French qualification programme.

- Two other tests are under discussions with other customers.

Conclusion
HFR is very interested in all new fuel development especially on high density fuel (UMo) and will be involved in these fuel tests in the near future.

## 5. Back end of the fuel cycle

- A contract was signed several years ago with COVRA (central organisation for radioactive waste) to build a storage facility for the HFR spent fuel. It is a dry storage of the elements in welded canisters with inert gas in the cavity. This storage facility should contain about 1400 elements. The building has begun this year, after licence authorisation and should continue until 2003.

- The maximal value of fuel element storage in the HFR pools, authorised by the safety authorities, has been reached in July 1999. Therefore, a provisory storage was necessary until 2003.
  In August 1999 we have loaded a container MTR 2, actually stored in the reactor containment and waiting a transfer to the COVRA site.

- After the future exchange of diplomatic notes, it will be possible to send back to USA the American origin, spent fuel.

  Several preparatory meetings were held with Savannah River representatives and with representatives of transport companies, to study the technical possibilities. Some budget problems remain and have to be resolved before any shipment.

Conclusion
Very positive events occurred in 1999 which now allow us to have several possibilities to manage the HFR spent fuel storage.

## 6. Conclusion

A lot of progress was made during the last year, on the HFR fuel cycle
- parametric study with final choice of one element for conversion to LEU
- beginning of licensing work of this fuel with safety authorities
- new possibilities for the spent fuel storage

## References

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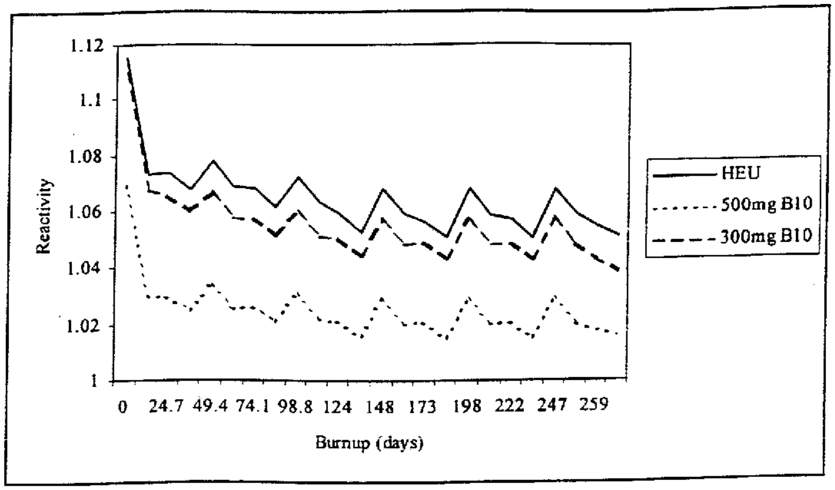


Fig. 1 : Parametric study. Example of the influence of Boron quantity in LEU on reactivity of the core

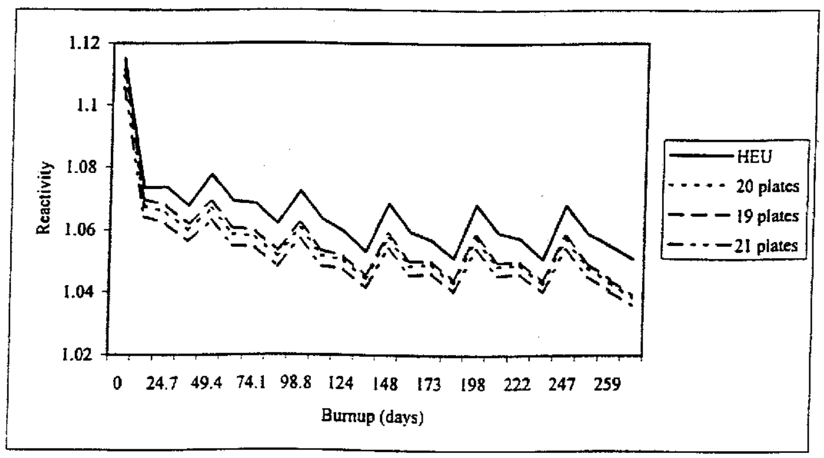


Fig. 2 : Parametric study. Variation in the number of plates (Silicide 4.8 g/cm$^3$, 0.76 mm, 300 mg Boron)

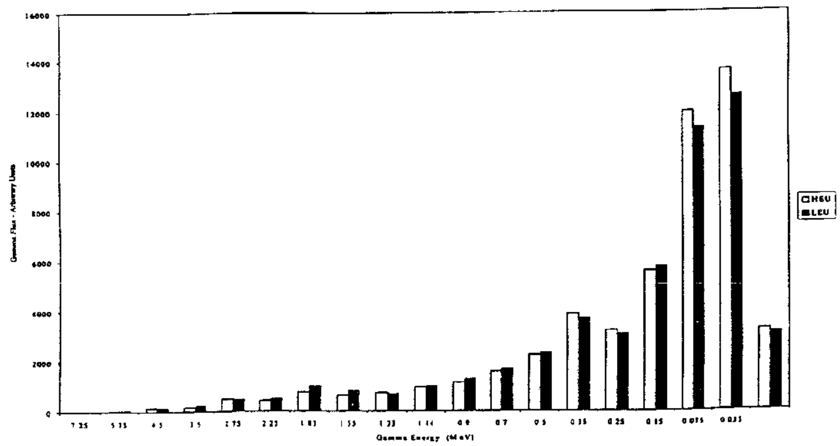


Fig. 3 : Comparison of the gamma flux at the PSF position

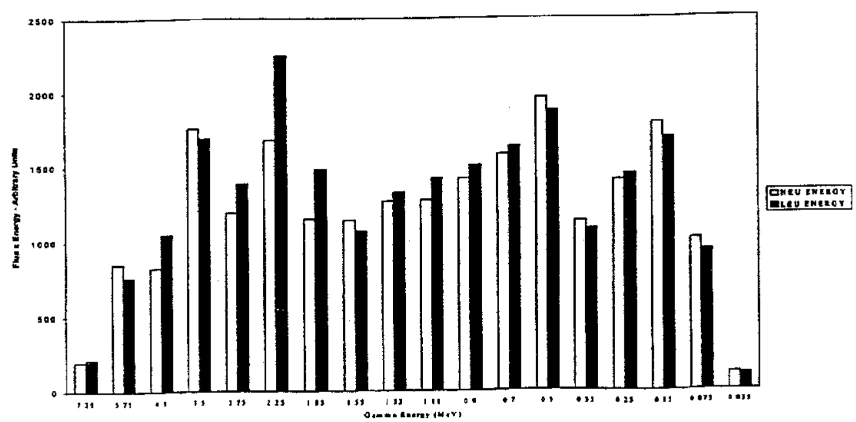


Fig. 4 : Comparison of the gamma energy at the PSF position

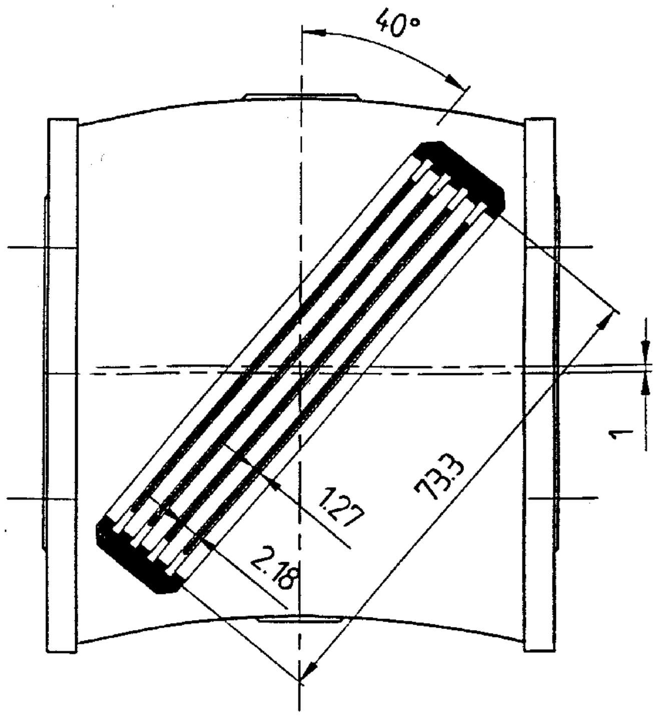


Fig. 5 : View of a MTR fuel test device to test four UMo plates in HFR